APPLICATION FOR A UNITED STATES PATENT

For

ACOUSTO-OPTIC TUNABLE APPARATUS
HAVING A FIBER BRAGG GRATING AND AN OFFSET CORE

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ACOUSTO-OPTIC TUNABLE APPARATUS

HAVING A FIBER BRAGG GRATING AND AN OFFSET CORE

FIELD OF THE INVENTION

[001]   This invention generally relates to performing one or more operations on a band of wavelengths within an optical signal. More particularly, an aspect of this invention relates to acousto-optic sideband generating technologies.

BACKGROUND OF THE INVENTION

[002]   Multiple channels of optical information may be carried within a single optical signal similar to multiple channels of television being transmitted to a consumer's home through a single cable TV signal. The multiple signals within the optical signal may be broadcast through a technique called dense wavelength division multiplexing which interweaves all the channels into a single photo optic signal. The International Telecommunications Union established a frequency grid spacing of one hundred GigaHertz (i.e. about eight tenths of a nanometer between adjacent channels of optical information. For example, five adjacent optical channels may be optical wavelengths of 1550.12 nanometers (nm), 1549.32 nm, 1548.51 nm 1547.72 nm, and 1546.92 nm. Thus, bandwidth of each channel is confined to a very narrow band of wavelengths, such as 1549.12 nm to 1549.52 nm (1549.32 nm +/- .2 nm) in order to prevent a first channel overlapping into an adjacent channel and distorting the information in both channels.

[003]   Acousto-optic technologies may use an acoustic wave to manipulate a photo optic signal traveling through an optical fiber. The acoustic wave may be used to manipulate a narrow band of wavelengths within the photo optic signal.

[004]   Several related acousto-optic sideband generating technologies have disadvantages that make those technologies commercially impractical. A first acousto-optic sideband generating technology and a second acousto-optic sideband generating technology generate longitudinal acoustic waves that induce accordion like ripples on a reduced diameter optical fiber containing a fiber Bragg grating. The optical fiber has a core that contains a fiber Bragg grating and a cladding that surrounds the core positioned in the center of the cladding. The diameter of the optical fiber is reduced to magnify the acoustic waves effect of vibrating the periodic gratings inscribed in the fiber Bragg grating. The vibrating fiber Bragg grating may be tuned to manipulate a particular band of wavelengths within the photo optic signal. In these technologies, without a reduced diameter optical fiber, a stronger amplitude acoustic wave is needed to achieve the desired tuning of the periodic gratings. If the vibration from the acoustic wave becomes too strong, then damage may occur to the optical fiber, especially where the optical fiber is being clamped in place.

SUMMARY OF THE INVENTION

[005]   Various methods and apparatuses are discussed that microbend a fiber Bragg

grating with a acoustic wave. The interaction between the acoustic wave and the fiber

Bragg grating reflects one or more Nth order sidebands of reflection wavelengths an

optical signal in order to couple the band of wavelengths within from a first mode to a

second mode. In an embodiment, an optical waveguide has an interaction region

containing the fiber Bragg grating, a cladding, and a core offset in respect to the cladding.

[006]   Other features and advantages of the present invention will be apparent from the

accompanying drawings and from the detailed description that follows below.

BRIEF DESCRIPTION OF THE DRAWINGS

[007]   The present invention is illustrated by example and not limitation in the figures of the accompanying drawings, in which like references indicate similar elements and in which:

Figure 1a is a block diagram of an embodiment of an acoustic wave exciter affixed to an optical waveguide that contains an interaction region, one or more fiber Bragg gratings, a cladding, and a core offset in respect to the cladding;

Figure 1b is an graph of an exemplary main Bragg band of wavelengths and Nth order sidebands of optical wavelengths reflected by the vibrated fiber Bragg gratings;

Figures 1c, 1d, and 1e are cross-sectional views of various embodiments of the optical waveguide having an offset core with respect to the cladding;

Figure 2a is a block diagram of the acoustic wave exciter transmitting an acoustic wave at a first frequency and at a first amplitude to the interaction region;

Figure 2b is a graph of an exemplary transmission through the acousto-optic device;

Figure 3a is a magnified view of an embodiment of the interaction region from Figure 1 and illustrates the effects of an embodiment of acoustic wave on the interaction region containing one or more fiber Bragg gratings and an offset core with respect to the cladding;

Figure 3b is a graph of an exemplary main Bragg wavelength and two first order sidebands reflected by the fiber Bragg grating;

Figure 4a and Figure 4b are block diagrams of embodiments of optical add/drop modules using acoustically induced coupling of wavelengths within an optical

signal from a first mode to a second mode to add or drop bands of wavelengths from the optical signal;

Figure 5a is an embodiment of a gain-flattening module using acoustically induced microbending of a fiber Bragg grating to couple a portion of a band of wavelengths from a first mode to a second mode; and

Figure 5b is a graph of four exemplary bands of wavelength in an optical signal, wherein each band of wavelengths corresponds to a particular optical channel.

DETAILED DESCRIPTION

[008]   In general, apparatuses, methods, and systems are described in which an acoustic wave exciter affixes to an optical waveguide that has an interaction region containing a fiber Bragg grating, a cladding, and a core offset in respect to the cladding. In an embodiment, the acoustic wave exciter transmits a transverse acoustic wave along the interaction region in order to operate upon an optical signal passing through the interaction region by microbending the fiber Bragg grating. For one embodiment, the acoustic wave may extract a band of wavelengths from the optical signal, eliminate the band of wavelengths from the optical signal, add a band of wavelengths to the optical signal, or perform another similar operation upon the optical signal.

[009]   Figure 1a is a block diagram of an embodiment of an acoustic wave exciter affixed to an optical waveguide that contains an interaction region, one or more fiber Bragg gratings, a cladding, and a core offset in respect to the cladding. For one embodiment, the acoustic wave exciter 102 may comprise of a amplifying member 114 such as a horn, an acoustic wave generator 116 such as a transducer, and a signal generator 118 such as an RF signal generator. The optical waveguide 104, such as an optical fiber, may include an interaction region 106 containing one or more fiber Bragg gratings 108, a cladding 110 and a core 112 offset in respect to the cladding 110. Further, one or more acoustic wave absorbers 120 may connect to the interaction region 106 at each end of the interaction region 106. Likewise, one or more heat sinks 122 may connect to each acoustic wave absorber 120. For one embodiment, the core 112 contains one or more fiber Bragg gratings 108. For an alternative embodiment, the cladding 110 contains one or more fiber Bragg gratings 108.

[0010]   For one embodiment, the acoustic wave exciter **102** generates an acoustic wave to be transmitted to the interaction region **106**. The signal generator **118** applies an RF signal to the acoustic wave generator **116** in order to induce the amplifying member **114** to propagate the acoustic wave. For one embodiment, the acoustic wave exciter **102** generates the acoustic wave at a first frequency that corresponds to a first order sideband of optical wavelengths **124** from each fiber Bragg grating **108**. The amplifying member **114** amplifies and transmits the acoustic wave to vibrate the interaction region **106**. For one embodiment, the acoustic wave is a transverse acoustic wave. For one embodiment, the acoustic wave is a longitudinal, torsional or any other type of acoustic wave. The transmitted acoustic wave effects the fiber Bragg grating **108** by increasing and decreasing the spacing, via straining and compression, of the periodic gratings **126** inscribed in the fiber Bragg grating **108**.

[0011]   Figure 1b is a graph of an exemplary main Bragg band of reflected wavelengths and Nth order sidebands of optical wavelengths reflected by the vibrated fiber Bragg gratings. The fiber Bragg gratings in a nominal static state reflect a main Bragg band of wavelengths **128** from an optical signal passing through the fiber Bragg grating. The center wavelength **130** of the main Bragg band of wavelengths **128** corresponds to the nominal spacing of the periodic gratings inscribed in the fiber Bragg grating. The swift increasing and decreasing of spacing between the periodic gratings causes the first order sideband of optical wavelengths **124** to be reflected in addition to the main Bragg band of wavelengths **128** being reflected. The acoustic wave interaction with the fiber Bragg grating causes the input signal to couple from a first mode to a

second mode. For one embodiment, coupling means transitioning energy from one spatial propagation mode to another spatial propagation mode.

[0012]   Figures 1c, 1d, and 1e are cross-sectional views of various embodiments of the optical waveguide having an offset core with respect to the cladding. Referring to figure 1c, a first embodiment of the optical waveguide **104a** has an elliptical shaped cladding **110a** and a core **112a** centered in a first lobe portion of the elliptical shaped cladding **110a**. The elliptical shaped cladding **110a** has an outer surface **132a**. The core **112a** being located closer to the outer surface **132a** of the cladding **110a** than if the core **112a** was centered **134a** in the cladding **110a**.

[0013]   Referring to Figure 1a, for one embodiment, the core **112** may be offset with respect to the cladding **110** to magnify the compression and straining of the fiber Bragg gratings **108** induced by the transmission of the acoustic wave along the interaction region **106**. The compression and straining effects from a transverse acoustic wave on the fiber Bragg gratings **108** is magnified by having the core location offset from the center of the cladding. Thus, a smaller amplitude acoustic wave may effect a less violent shaking of the interaction region **106** to achieve a desired straining and compression of the periodic gratings **126** in the fiber Bragg grating **108**. For one embodiment, the interaction region **106** is reduced in diameter. For one embodiment, the interaction region **106** is nominal size in diameter.

[0014]   Referring to Figure 1d, a second embodiment of the optical waveguide **104b** has a D-shaped cladding **110b** and a core **112b** near the surface in the D-shaped cladding **110b**. After the optical waveguide **104b** is manufactured a top lobe of the elliptical cladding **110b** is removed in order to position the core **112b** closer to the outer

surface **132b**. Thus, the position of the core **112b** is closer to the outer surface **132b** of the cladding **110b** and offset in respect to the center **134b** of the remaining cladding **110b**.

[0015]   Referring to Figure 1e, a third embodiment of the optical waveguide **104c** has a circular shaped cladding **110c**, a core **112c** offset from the center of the circular shaped cladding **134c**, and optionally a structural protective casing **136c** such as a jacket.

[0016]   Referring to Figure 1a, the interaction region **106** in the optical waveguide **104** is where the structural protective casing **136** is removed. For one embodiment, the optical waveguide **104** may be manufactured without a structural protective casing **136** and the interaction region **106** is positioned between the acoustic transducer and acoustic wave absorber **120**. The absence of the structural protective casing **136** prevents absorption of the acoustic wave traveling along the interaction region. A section of the cladding **110** in the interaction region **106** may be tapered to further magnify the microbend effects on the fiber Bragg gratings **108** caused by the vibration of the acoustic wave.

[0017]   For one embodiment, the one or more fiber Bragg gratings **108** may consist of two or more portions. For one embodiment, the first portion **138** is discrete from the second portion **140** and an interruption of the fiber Bragg grating **108** exists between the second potion **140** and the first portion **138**. For one embodiment, the fiber Bragg grating **108** is continuous from the first portion **140** to the second portion **138** (not illustrated).

[0018]   Figure 2a is a block diagram of an embodiment of the acoustic wave exciter transmitting an acoustic wave at a first frequency and at a first amplitude to the interaction region. As noted in Figure 1, an embodiment of the acoustic wave exciter **202**

may include a signal generator **218**, an acoustic wave generator **216**, and an amplifying member **214**. The signal generator **218** can vary both the amplitude and the frequency of the RF signal applied to the acoustic wave generator **216**. The acoustic wave generator **216** transmits the acoustic wave along the interaction region **208**.

[0019]   Figure 2b is a graph of an exemplary transmission through the acousto-optic device . The acoustic wave is generated at a given frequency and at a given signal strength such as a first frequency **204** and at a first amplitude **208**. Due to the microbending of the fiber Bragg grating, the vibrated fiber Bragg grating generates the first order sidebands of reflected wavelengths. A mathematical relationship exists between the frequency of the generated acoustic wave, such as the first frequency **204**, and the coupled center wavelength (λc) **222** of the Nth order sidebands of the optical signal.

[0020]   An incoming optical signal may contain multiple channels of optical information. Each channel may be a narrowly defined band of wavelengths within the optical signal. As noted above, a spacing of about eight tenths of a nanometer exists between adjacent channels of optical information on the International Telecommunications Union frequency grid. Each channel corresponding to a particular center optical wavelength. For example, five adjacent optical channels may have center optical wavelengths of 1550.12 nanometers (nm), 1549.32 nm, 1548.51 nm 1547.72 nm, and 1546.92 nm. Thus, bandwidth of each channel is confined to a very narrow band of wavelengths, such as 1549.12 nm to 1549.52 nm (1549.32 nm +/- .2 nm). The optical signal passing through the one or more fiber Bragg gratings may contain, for example, forty channels of optical information.

[0021]   The signal generator controls the frequency and amplitude of the acoustic wave in order to operate upon one or more of the individual channels within the optical signal passing through the interaction region **206** without affecting the remaining channels. The first frequency **204** determines which first order sideband center wavelength is reflected. For example, the first frequency **204** could correspond to microbending the fiber Bragg grating to reflect a narrow first order sideband of reflected wavelengths centered on 1547.72 nm. The magnitude of the first amplitude **208** determines the percentage of the narrow band of wavelengths centered on 1547.72 nm coupled from a first mode, such as a forward traveling core mode, to a second mode, such as a backward traveling core mode or cladding mode. The periodic spacings of the fiber Bragg gratings determines the center of the band of wavelengths reflected such as center wavelength (λc) **222.** The number of periodic gratings in the fiber Bragg gratings determines the width of the band of wavelengths reflected such as a first band **220** of wavelengths within the optical signal. Likewise the signal generator **218** may generate a second frequency **219** at a second amplitude **212** to manipulate a second band **210** of wavelengths within the optical signal. For example, the second frequency **219** could correspond to microbending the fiber Bragg grating to reflect a narrow first order sideband of wavelengths centered on 1549.32 nm.

[0022]   Figure 3a is a magnified view of an embodiment of the interaction region from Figure 1 and illustrates the effects of an embodiment of acoustic wave on the interaction region containing one or more fiber Bragg gratings and an offset core with respect to the cladding. For one embodiment, the interaction region **306** contains cladding **312** and a core **310** offset in respect to the center of the cladding **312**. The interaction region **306**

also contains one or more fiber Bragg gratings **308**. For one embodiment, each fiber Bragg grating **308** is continuous from the first potion **338** to the second portion **340**.

[0023] For one embodiment, when the acoustic wave flexes the interaction region downward the first portion **338** of the periodic gratings in the fiber Bragg grating **308** compress to decrease the spacing between each grating. When the acoustic wave flexes the interaction region **306** upward the second portion **340** of the periodic gratings in the fiber Bragg grating **308** strains to increase the spacing between each grating. The cyclic stretching and compressing of the space between the gratings causes the first order sideband of wavelengths to be reflected.

[0024] Figure 3b is a graph of an exemplary main Bragg wavelength and two first order sidebands reflected by the fiber Bragg grating. The graph illustrates a main Bragg wavelength **328** having a center wavelength of 1525 nm **342** and two first order sidebands **324**. One of the first order sidebands **324** has a center wavelength of 1535 nm **344**. As noted, the acoustic wave frequency and amplitude controls the spectral location and intensity of the first order sideband of reflected wavelengths **324**, respectively. For one embodiment, the first order sideband of reflected wavelengths **324** are spectrally located on both sides of the main Bragg band of reflected wavelengths **328**.

[0025] The main Bragg band of reflected wavelengths **328** may have a center wavelength of 1525 nm **342** and the first order sideband of reflected wavelengths **324** may have a center wavelength **344** spectrally located 10 nm displaced away from the main Bragg wavelength **342**. For one embodiment, the spectral location of the first order sideband reflected wavelengths is based upon the acoustic wave frequency, the phase index of the optical waveguide, and the center wavelength of the fiber Bragg grating. For

one embodiment, each first order sideband of reflected wavelengths 324 is equally

displaced from the main Bragg wavelength 342 due to the frequency of the acoustic wave.

The overall spectral shape and center wavelength of the main Bragg band of reflected

wavelengths 328 corresponds to the nominal spacing and strength of the periodic gratings

inscribed in the fiber Bragg grating.

[0026]   For one embodiment, the strength of first order sidebands of wavelengths 324

follows a Bessel function similar to the case for frequency modulation of a sinusoidal

wave. The index of refraction changes for the mode that the optical signal is propagating

through due to the microbending effects on the fiber Bragg grating. The changed index of

refraction may cause the coupling between modes.

[0027]   The simultaneous increasing and decreasing of spacing between the periodic

gratings of the fiber Bragg grating 308 causes the first order sideband of reflected

wavelengths 324 to be reflected in addition to the main Bragg band of reflected

wavelengths 328. For one embodiment, the spectral shape of the first order sideband of

reflected wavelengths 324 replicate the spectral shape of the main Bragg band of reflected

wavelengths 328.

[0028]   Referring to figures 3a and 3b, the acoustic wave induced vibration and hence

microbending of the fiber Bragg grating 308 causes coupling between a first mode such

as a forward propagation core mode, and a second mode such as a counter propagating

cladding mode. For one embodiment, if the striations of the gratings are perpendicular to

the incoming optical signal then the reflected wavelengths within the optical signal may

be coupled from the forward propagation core mode to the counter propagation core

mode. For one embodiment, if the striations of the gratings are not perpendicular to the

incoming optical signal then the reflected wavelengths within the optical signal may be coupled from the forward propagation core mode to the counter propagation cladding mode. For one embodiment, if the striations of the gratings are not perpendicular to the incoming optical signal then the reflected wavelengths within the optical signal may be coupled from the forward propagation core mode to a backward propagating cladding mode. Thus, the incoming optical signal may be separated into a forward optical signal propagating past the fiber Bragg grating **308** and a reflected optical signal reflected from the fiber Bragg grating **308**. The forward optical signal may be collected at the output **346** of the interaction region and routed to another optical component. Similarly, the reflected optical signal may be collected and routed to another optical component.

[0029]   Figure 4a and Figure 4b are block diagrams of embodiments of optical add/drop modules using acoustically induced coupling of wavelengths within an optical signal from a first mode to a second mode to add or drop bands of wavelengths from the optical signal.

[0030]   Referring to Figure 4a, for one embodiment, a drop module **400a** consists of a circulator **402a**, an acoustic wave exciter **404a**, an optical waveguide **406** having an interaction region **408a** containing a fiber Bragg grating **410a**, a cladding **412a**, and a core **414a** offset in respect to the cladding **412a**, an acoustic wave absorber **416a**, and a heat sink **418a**.

[0031]   For one embodiment, the incoming optical signal contains multiple optical channels of wavelengths. For example, the incoming signal may contain forty channels included within the spectrum of 1532.0 nm to 1562.0 nm. The circulator **402a** routes the incoming optical signal in the forward direction to the interaction region **408a**. The main

Bragg wavelength may be set to a center wavelength outside the spectrum of the optical signal such as 1528 nm. Thus, the main Bragg band of reflected wavelengths will not affect the optical signal. The vibrated fiber Bragg grating **410a** also reflects the first order sideband of reflected wavelengths that can be spectrally located within the spectrum of the optical signal. As noted above, the frequency of the acoustic wave determines the center wavelength of the first order sideband. Thus, a band of wavelengths corresponding to a single channel may be reflected out of the optical signal to leave the remaining optical channels, thirty-nine in this example, propagating through the output **422a** of the drop module **400a**. Also, a single channel reflects back, for example, in a counter propagational core mode toward the circulator **402a**. The circulator **402a** may route the reflected signal to drop output **419a** from the circulator **402a**. Similarly in an embodiment, the band of wavelengths corresponding to the single channel may be coupled into a cladding mode by microbending the fiber Bragg grating.

[0032]   Referring to Figure 4b, for one embodiment, an add module **400b** consists of a circulator **402b**, an acoustic wave exciter **404b**, an optical waveguide **406b** having an interaction region **408b** containing a fiber Bragg grating **410b**, a cladding **412b**, and a core **414b** offset in respect to the cladding **412b**, an acoustic wave absorber **416b**, and a heat sink **418b**.

[0033]   For one embodiment, the incoming optical signal contains multiple optical channels of wavelengths. For example, the incoming signal may contain thirty-nine channels contained within the spectrum of 1530 nm to 1562 nm and missing the 1550 nm optical channel. The incoming optical signal propagates in a forward direction into the interaction region **408b**. A circulator **402b** receives an optical signal that adds the

missing 1550 nm optical channel. The circulator **402b** may route the 1550 nm optical channel into the interaction region **408b**. The acoustic wave exciter **404b** adjusts the frequency of the acoustic wave to cause the fiber Bragg grating **410b** to reflect the first order sideband, the 1550 nm optical channel. The 1550 nm optical channel propagates with the other thirty-nine channels through the circulator **402b** to the output **422b** of the circulator **402b**. For one embodiment, using mode coupling as the means to manipulate the optical signal the insertion loss on the optical signal passing through the interaction region **404b** is very low.

[0034]   For one embodiment, the optical signal can travel in multiple modes such as forward propagating core to counter propagating core, core to cladding, polarization to polarization, multiple cladding modes to a single core mode, and other similar optical modes.

[0035]   Figure 5a is an embodiment of a gain-flattening module using acoustically induced microbending of a fiber Bragg grating to couple a portion of a band of wavelengths from a first mode to a second mode.

[0036]   For one embodiment, a gain flattening module **500** consists of a first acoustic wave exciter **504**, an optical waveguide **506** having a first interaction region **508** containing a first fiber Bragg grating **510**, a first cladding **512**, and a first core **514** offset in respect to the first cladding **512**, a first acoustic wave absorber **516**, and a first heat sink **518**. The gain flatting module also has a second acoustic wave exciter **520**, a second interaction region **522** containing a second fiber Bragg grating **524**, a second cladding **526**, and a second core **528** offset in respect to the second cladding **526**, a second acoustic wave absorber **530**, and a second heat sink **532**.

[0037]   For one embodiment, the percentage of the first order sideband of wavelengths reflected from a first mode to a second mode is based upon the amplitude of acoustic wave, the proximity of the fiber Bragg gratings to the outer surface of the optical waveguide, the coupling constant of the fiber Bragg grating for that mode, and the phase index of the optical waveguide. Thus, all or just a portion of the reflected wavelengths within the optical signal may be removed from the optical signal.

[0038]   Figure 5b is a graph of four exemplary bands of wavelength in an optical signal, wherein each band of wavelengths corresponds to a particular optical channel. The optical signal may contain a first channel of wavelengths 532, a second channel of wavelengths 534, a third channel of wavelengths 536, and a fourth channel of wavelengths 538. The third channel of wavelengths 536 may have a higher signal strength than the other three channels 532, 534, 538.

[0039]   As noted above, an entire reflected band of wavelengths corresponding to an optical channel of information may be removed from the optical signal. Also, if the reflected band of wavelengths corresponds to an optical channel of information that possess a signal strength out of proportion with the other channels, then a slight percentage of the reflected band of wavelengths may be removed, via coupling, from the optical signal in order to even out the signal strength of all the channels of information within the optical signal. Thus, the optical signal may be spectrally shaped by selectively removing one or more portions of the optical wavelength spectrum contained in the optical signal. One hundred percent or less of the band of wavelengths may be removed, via coupling, from the optical signal.

[0040]   Referring to Figure 5a and Figure 5b, the first acoustic wave exciter **504**

transmits an acoustic wave having a frequency that causes the first fiber Bragg grating

510 to reflect the band of wavelengths corresponding to the third channel of wavelengths

536. The amplitude of the acoustic wave is tuned such that only a small percentage of the

third channel of wavelengths **536** is coupled from a first mode, such as the forward

propagating core mode, to a second mode such as a cladding mode. A feedback loop (not

shown) from the output **540** of the gain flatting module **500** to the first acoustic wave

exciter **504** to determine the percentage of the third channel of wavelengths **536** needed to

be eliminated to make the signal strength of the third channel equal with the rest of the

channels.

[0041]   Multiple interaction regions, such as the first interaction region **508** and the

second interaction region **522** may be cascaded to manipulate multiple channels within

the same optical signal. Each interaction region **508, 522** operates on one or more bands

of wavelengths in the optical signal.

[0042]   Various other configurations and implementations exist. For one embodiment,

the optical waveguide may be an optical fiber. For one embodiment, the optical wave-

guide comprises a single mode optical fiber. For one embodiment, the optical waveguide

may be a multi-mode fiber. For an alternative embodiment, the Nth order of sideband

wavelengths may be used in addition to or instead of the first order of sideband

wavelengths. For one embodiment, multiple named components such as fiber Bragg

gratings or acoustic wave exciters may exist in an embodiment. For one embodiment,

optical components having similar functions to the components described above may

exist. For an alternative embodiment, one or more acoustic waves may be transmitted to the same interaction region.

[0043]   For additional embodiments, most functions performed by electronic hardware components may be duplicated by software emulation. In the forgoing specification, the invention has been described with reference to specific exemplary embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention as set fourth in the appended claims. The specification and drawings are, accordingly, to be regarded in an illustration rather then a restrictive sense.